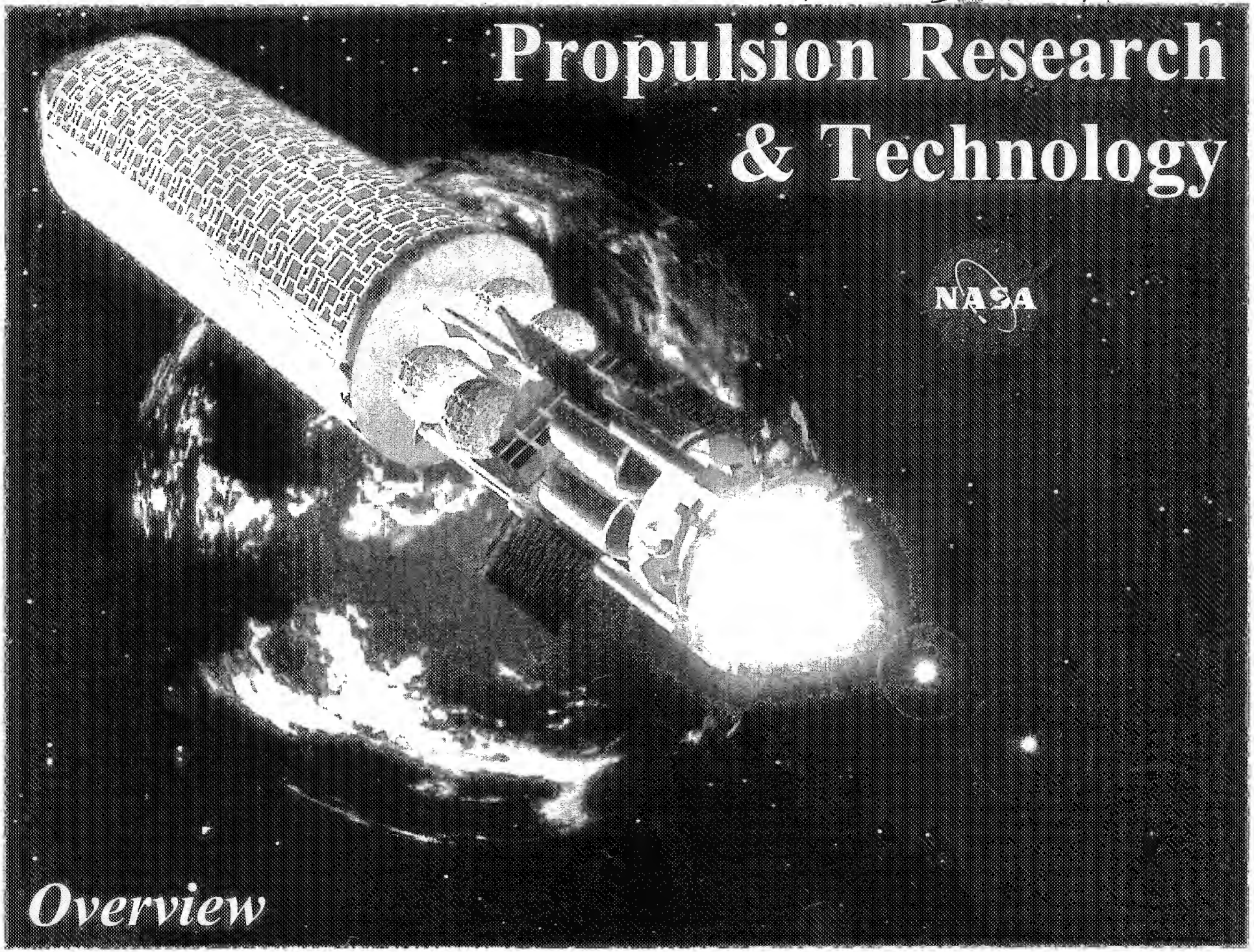
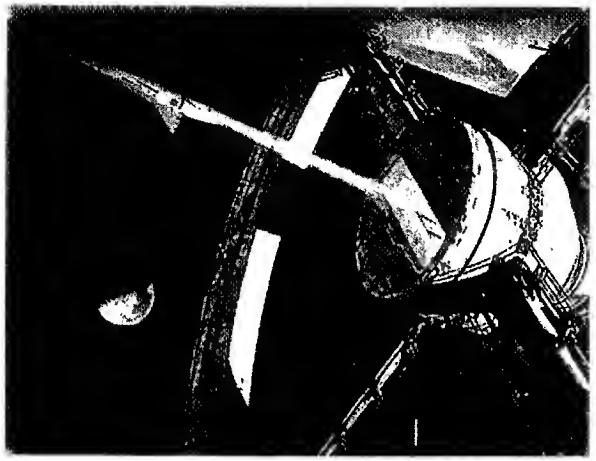
Propulsion Research & Technology



NASA

Overview

Importance to the future



Propulsion is unique in being the main delimiter on *how far* and *how fast* one can travel in space.

It is the *lack* of truly economical high-performance propulsion systems that continues to *limit and restrict* the extent of human endeavors in space.

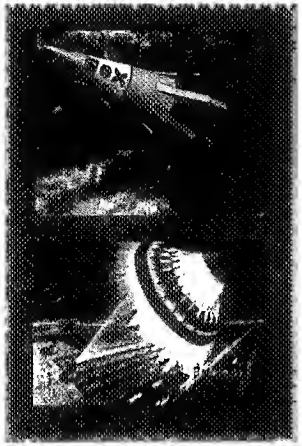
Our mission

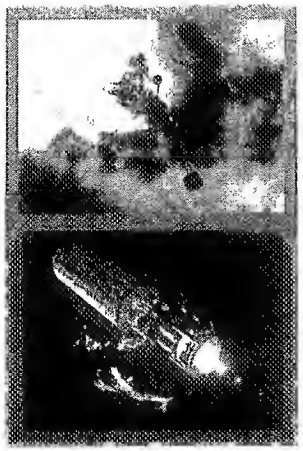
The Grand Vision

- ***Human colonization*** **and settlement of other planets and star systems**
- ***Exploration*** **to expand understanding of the universe**
- ***Commercial development*** **and utilization of extraterrestrial resources**

- ***Conceive and investigate new, revolutionary propulsion concepts***
- ***Demonstrate critical functions of promising technologies - perform proof-of-concept***
- ***Perform leading-edge development***

Organization

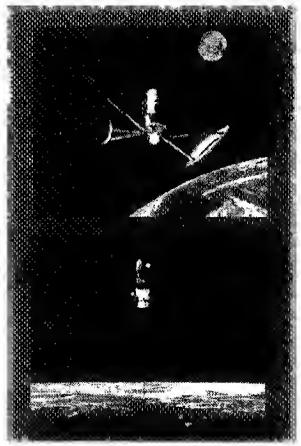




LAUNCH APPLICATIONS

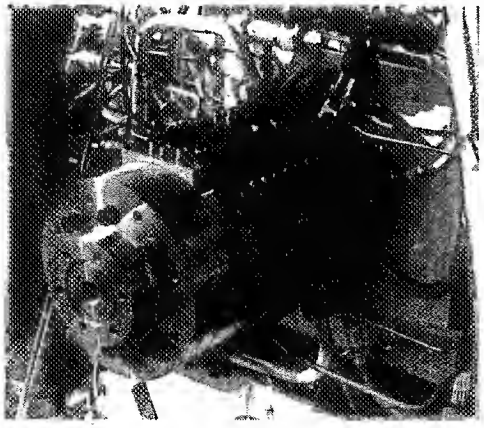
SPACE APPLICATIONS

ADVANCED HIGH-ENERGY CONCEPTS



Rocket Components & Processes

Application of Raman Scattering diagnostic procedure



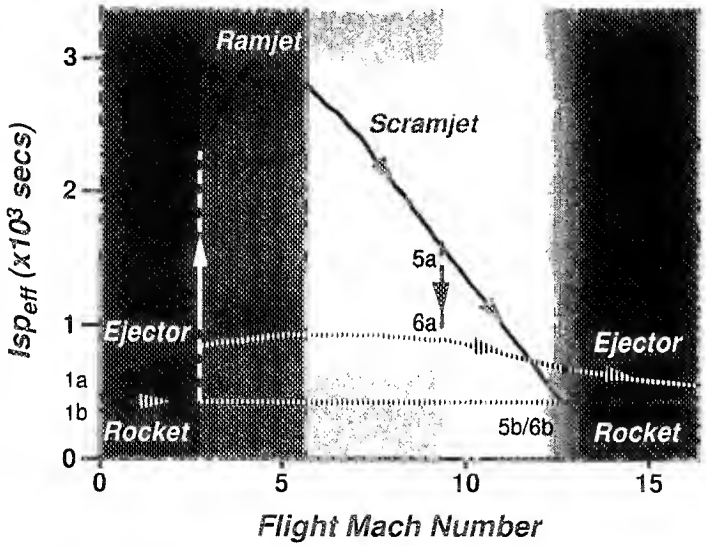
Uni-Element Combustion Chamber

Chemical Injector Technology

Combustion Physics

Advanced Fuels & Propellants

Airbreathing Propulsion



RBCC engine test article at GASL

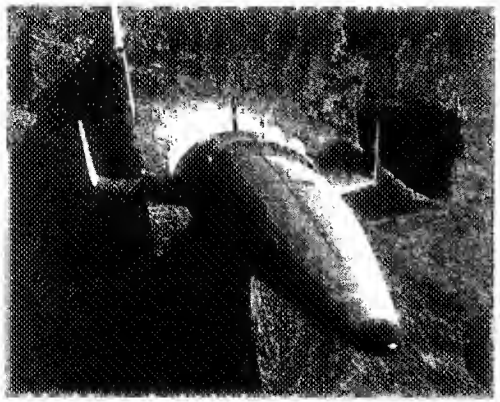
Rocket-Based Combined Cycle (RBCC) Propulsion

- Subscale Ground Tests
- System Modeling & Analysis
- Flight Experiments

Alternative Combined Cycles

- Methanol Ramjet Demonstration
- Liquid Air Cycle Engines (LACE)

Advanced Launch Systems



RBCC SSTO vehicle with launch assist

One of the original indoor flight tests

Laser Propulsion

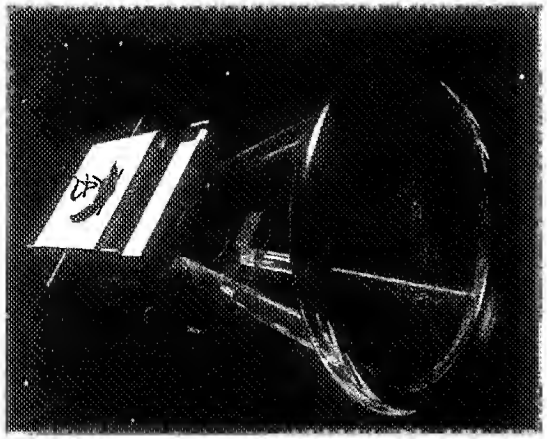
- Laser Pulsejet Technology
- Lightcraft Flight Experiments - WSMR

Launch Assist Concepts

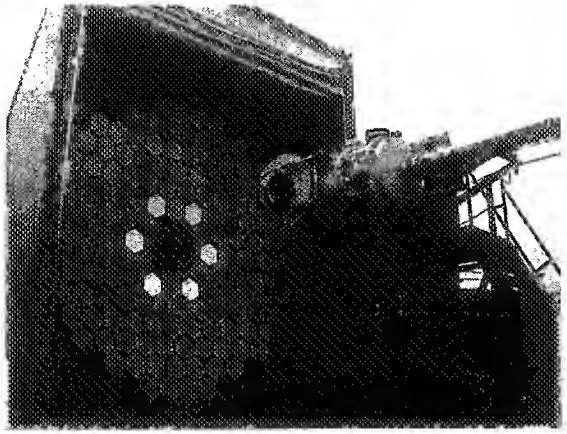
- Maglifter

Pulse Detonation Engines

Solar Thermal Propulsion



Shooting Star Flight Experiment Concept



Solar Thermal Test Facility Concentrator

Direct-Gain Engine Research

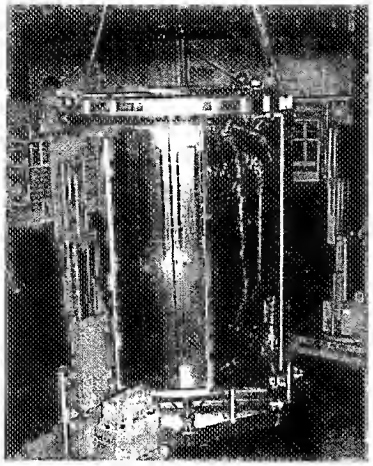
Ground Technology Demos

- Joint NASA/AF/Industry AITP
- Shooting Star Technology

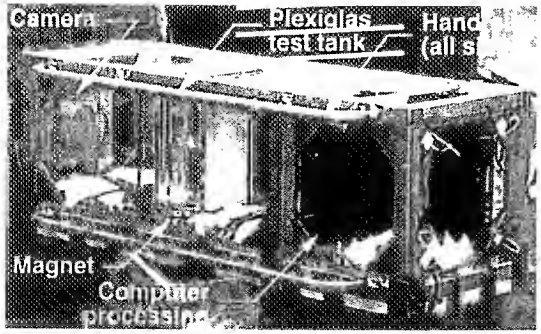
SOTV Flight Experiment

- Joint AF/Industry/NASA

Low-G Cryo Fluid Management



MHTB tank enclosed within heater shield



KC-135 free-floating MAPO experiment package

Multipurpose Hydrogen Test Bed (MHTB)

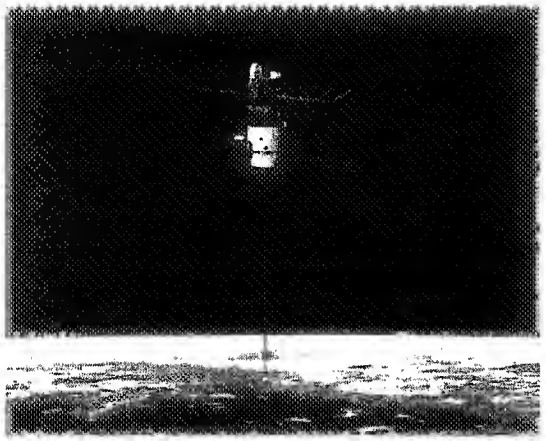
- Thermal & Pressure Control Subsystems
- Liquid Acquisition Devices
- Low-G Fluid Quantity Gaging

Flight Experiments

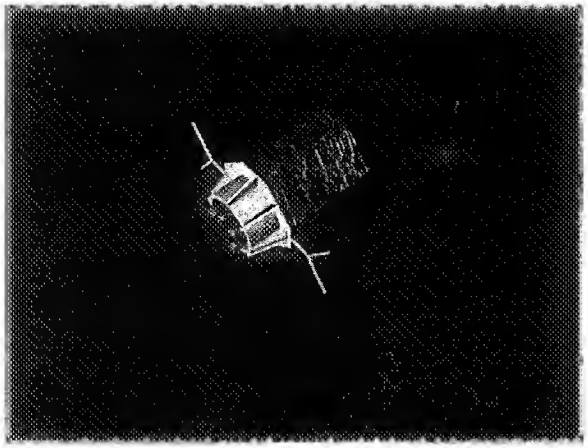
Advanced Concepts

- Magnetically-Actuated Propellant Control
- Hydrogen Carbon Matrix Storage

Electric Propulsion



Earth-orbiting electrodynamic tether



NSTAR Ion-propelled spacecraft

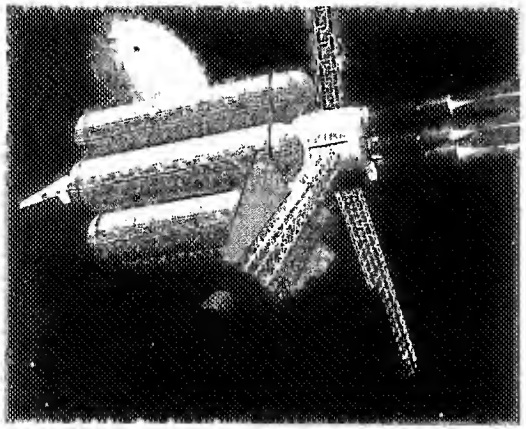
Electrodynamic Tethers

- PROSEDS Flight Experiment
- Jovian Probe

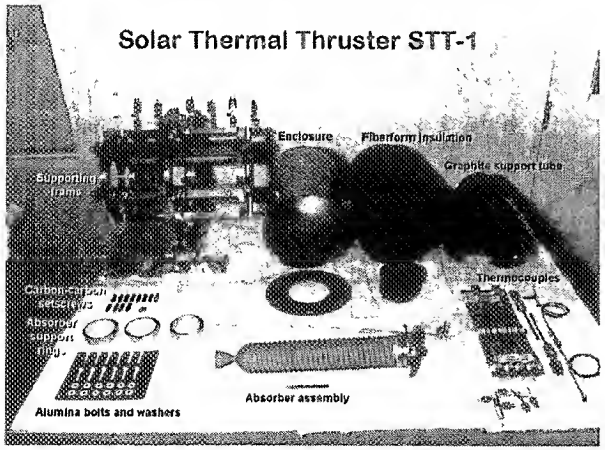
Electromagnetic Thrusters

- Pulsed Inductive Thruster (PIT)
- Plasmoid Thrusters

Nuclear Propulsion



Variable Isp Propulsion System



Bimodal heat-pipe simulation tests

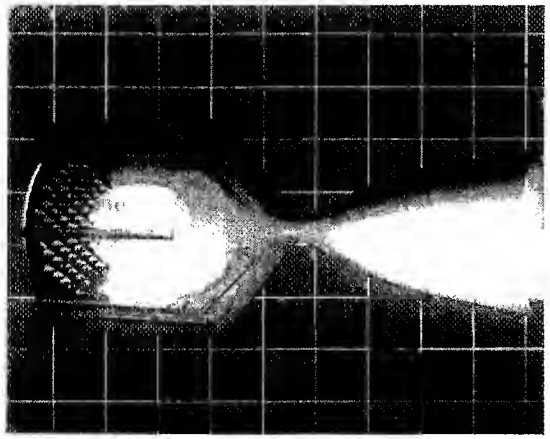
Simulated Nuclear Tests
- Bimodal reactor system

Nuclear Electric Flight Test
- Saturn Ring Orbiter Mission
- Asteroid Deflection Demonstration

Interstellar Precursor Mission

Human Exploration Studies
- High-Thrust Nuclear Electric
- Nuclear Thermal Engines

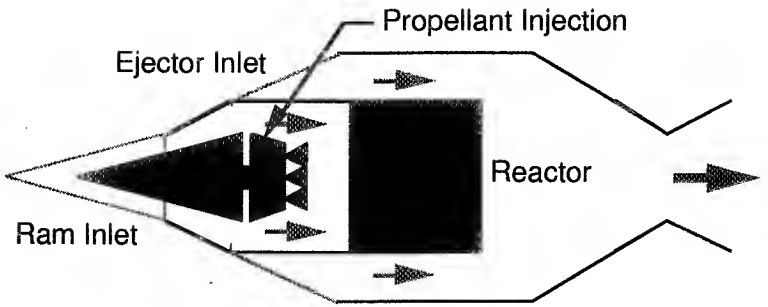
Advanced Nuclear Processes



Gas Core Fission Rocket

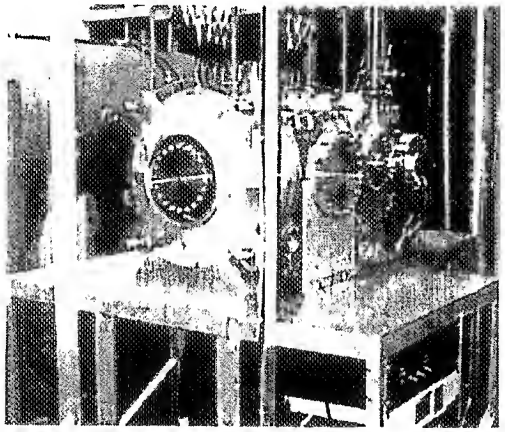
Gas-Core Nuclear Propulsion

Hot Isomeric Transitions

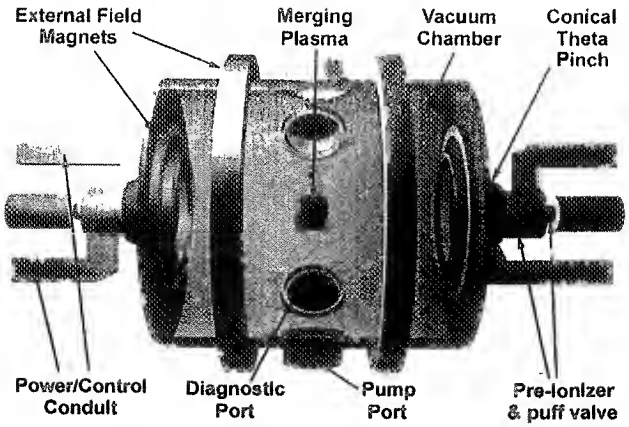


Isomer-Based Ejector Ramrocket

Fusion Propulsion



Electron-beam Heating/Nozzle Experiment



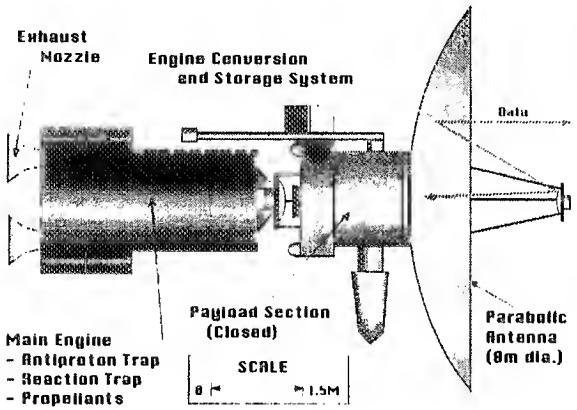
Plasma Target Generator Experiment

Magnetized Target Fusion (MTF)

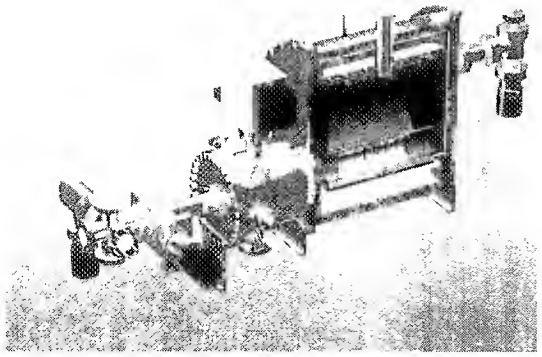
Inertial Electrostatic Confinement (IEC)

Magnetic Confinement

Antimatter Technology



AIM-STAR AIM-powered interstellar probe



High Performance Antimatter Trap (HiPAT)

Production
- Low-cost Degrader/Accumulator
- Vacuum Energy Suppression

Storage
- High-Performance Antiproton Trap
- Plasmoid Thrusters

Energy Utilization
- Compressed Target Interaction Exp
- Antimatter Plasma Heating/Thrust

Summary

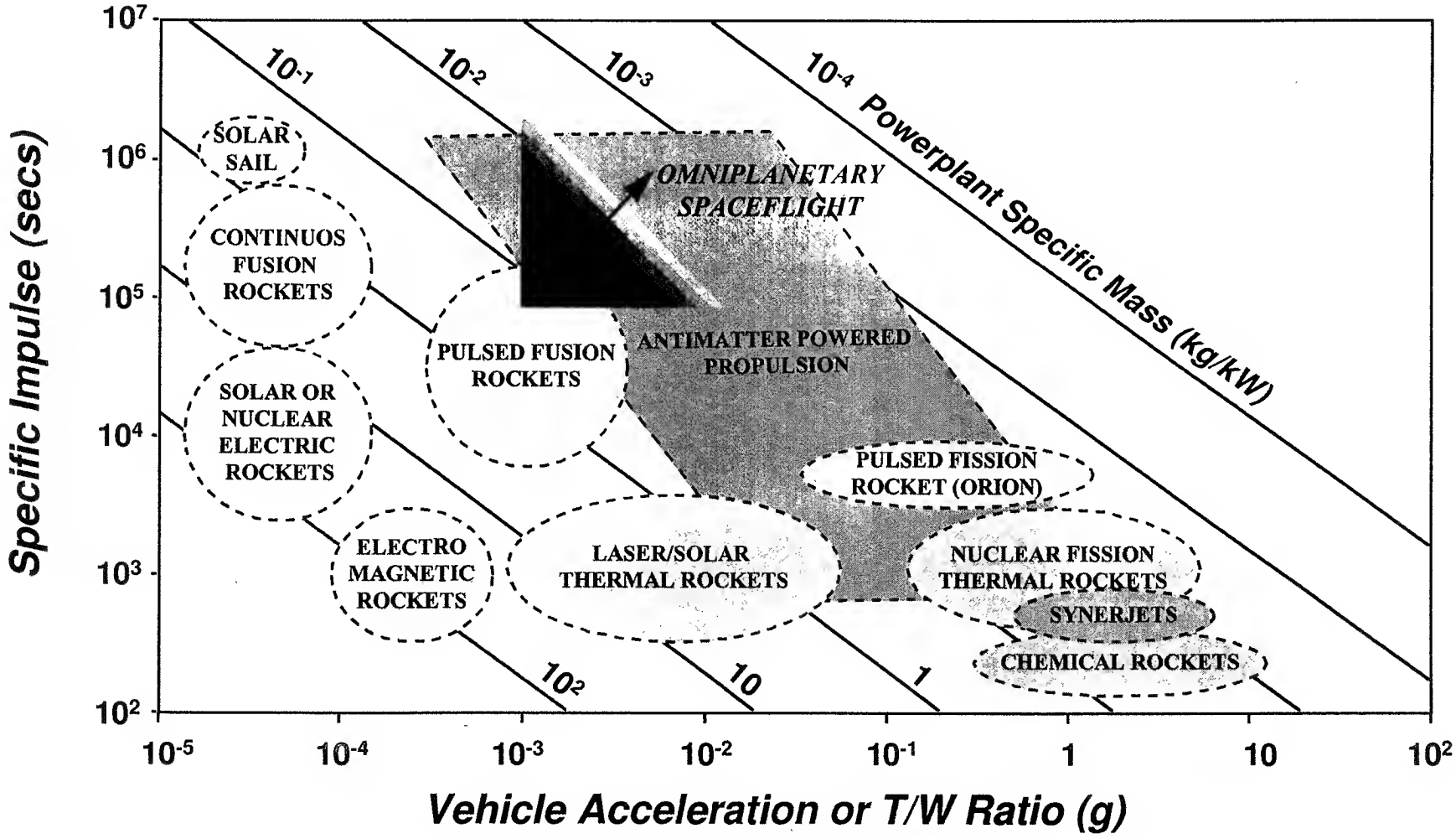
- **Research focused on the most challenging propulsion technologies needed to *Open Up The Frontier***

- **Take advantage of resources inside & outside MSFC**
  - **Collaborations & leveraged programmatic resources**
  - **Visiting researcher programs**

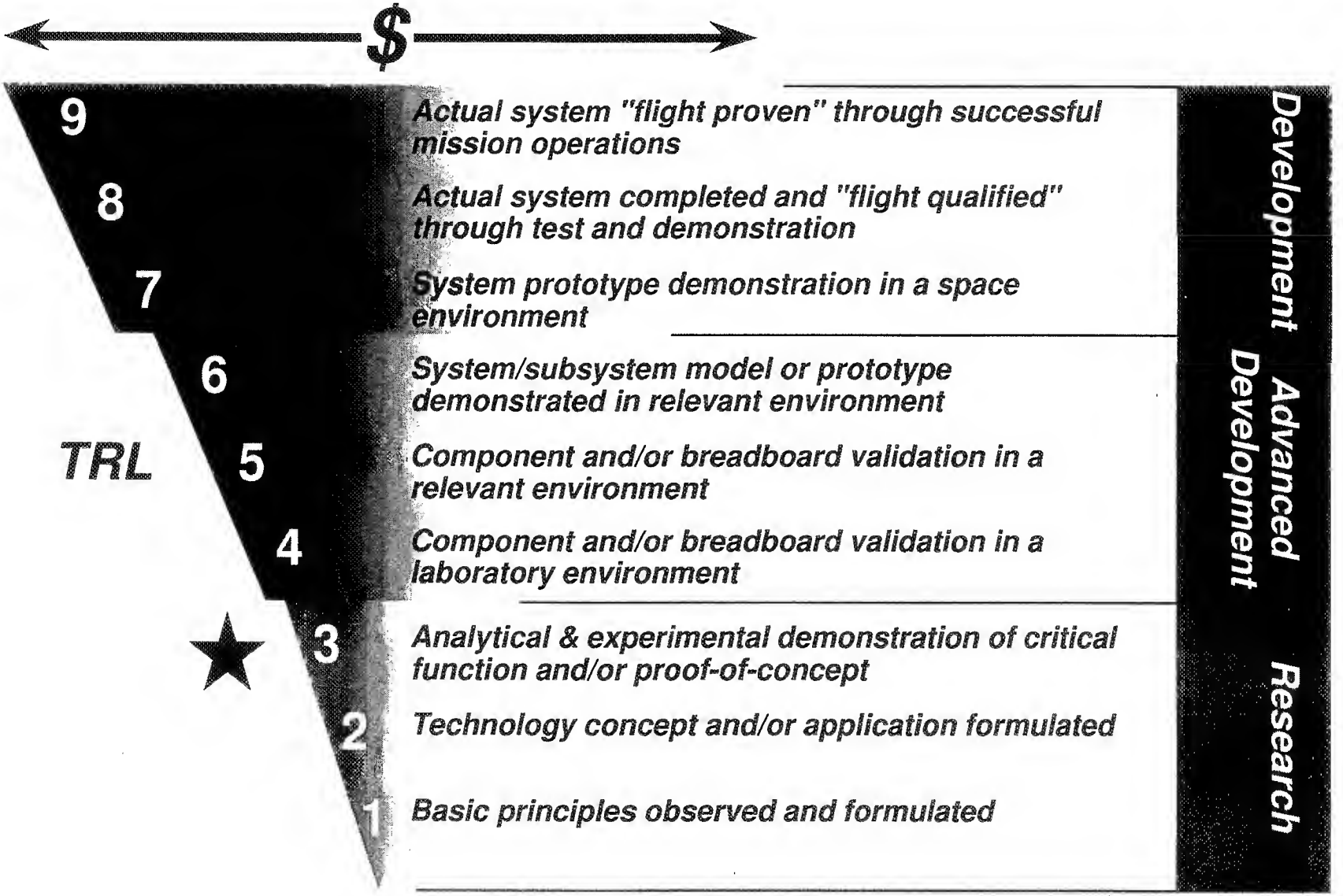
- **Emphasize small, relatively inexpensive research activities**
  - **Subscale investigations of promising technologies**
  - **Proof-of-concept demos (TRL 3) "set stage" for advanced development**

- **Goals & future directions**
  - **Flight demonstration of new, high-performance launch concept(s)**
  - **Experimentally prove viability of omniplanetary/interstellar propulsion concept(s)**
  - **Provide technologies to enable *ambitious* robotic exploration of solar system & near-interstellar space - bimodal nuclear, high-thrust electric, and micro-spacecraft propulsion**

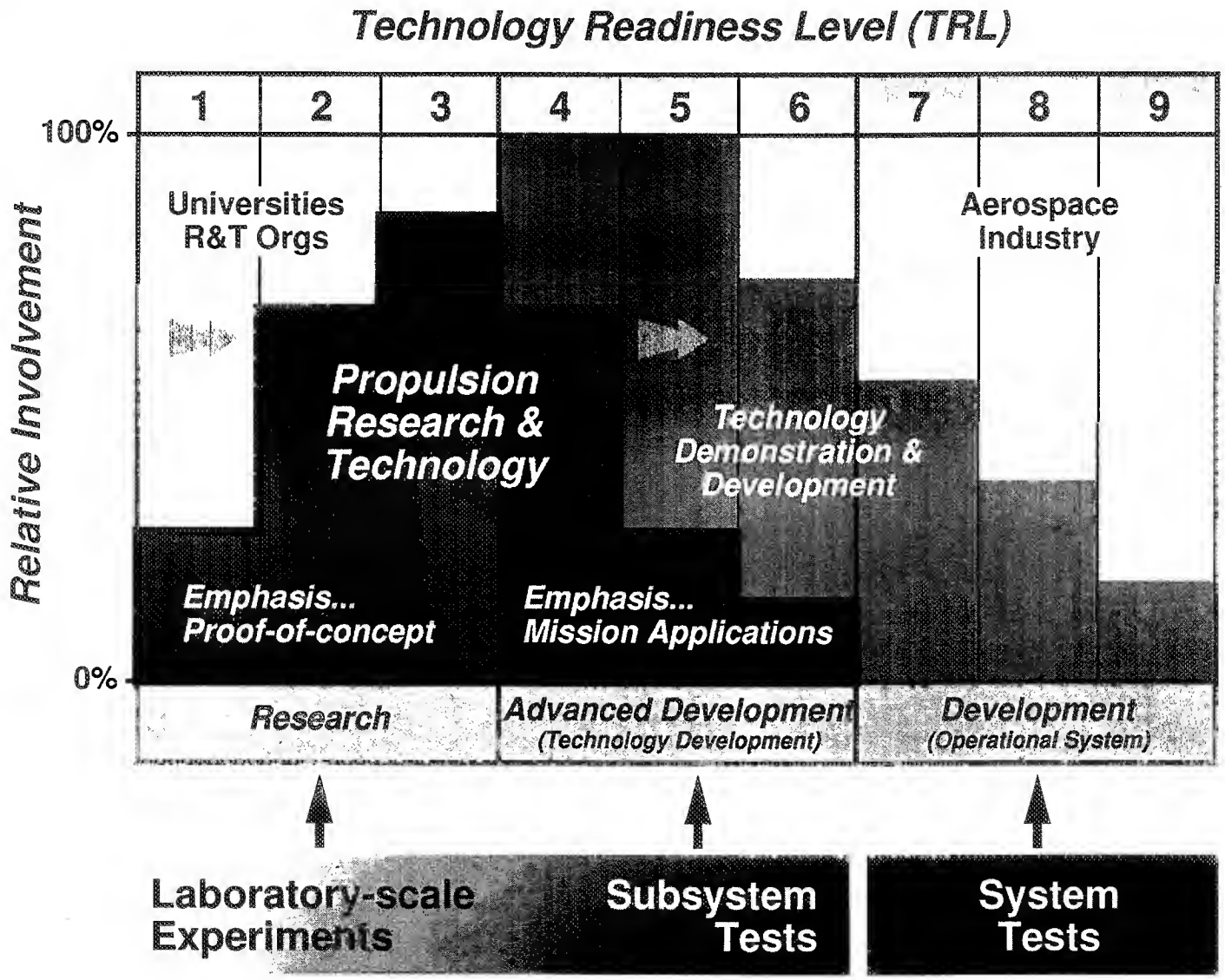
General Performance of Various Propulsion Concepts



Technology Readiness Levels (TRL)

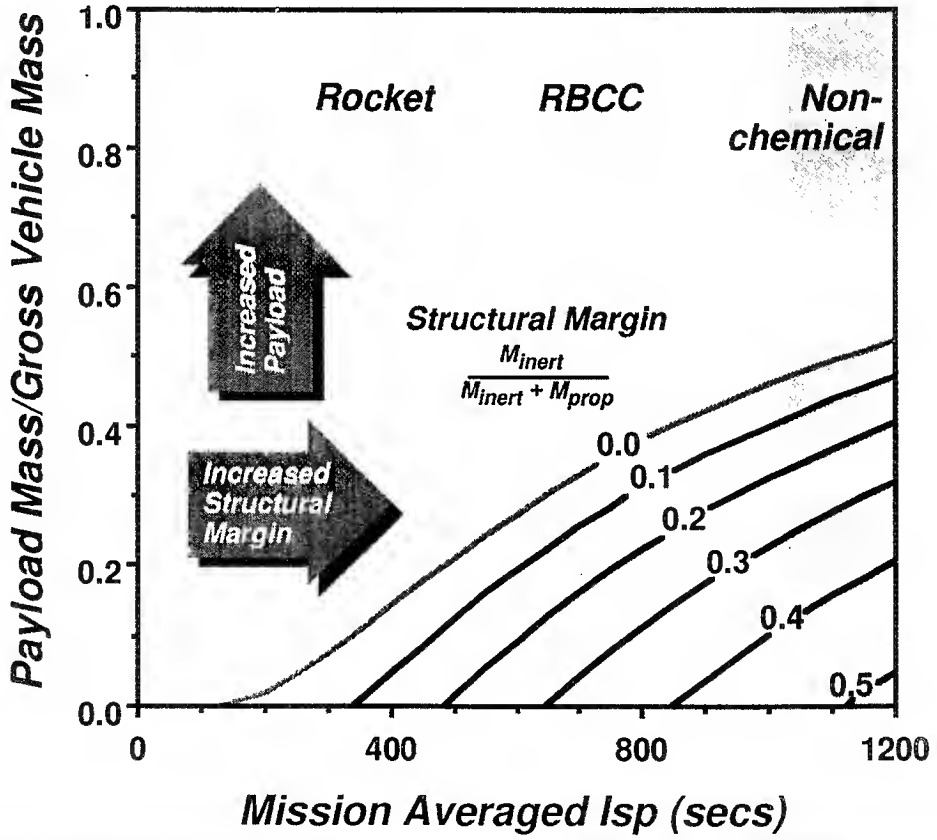


A bridge linking concept to advanced development...



Research Goals - Launch

Requirements to reach 270 km orbit

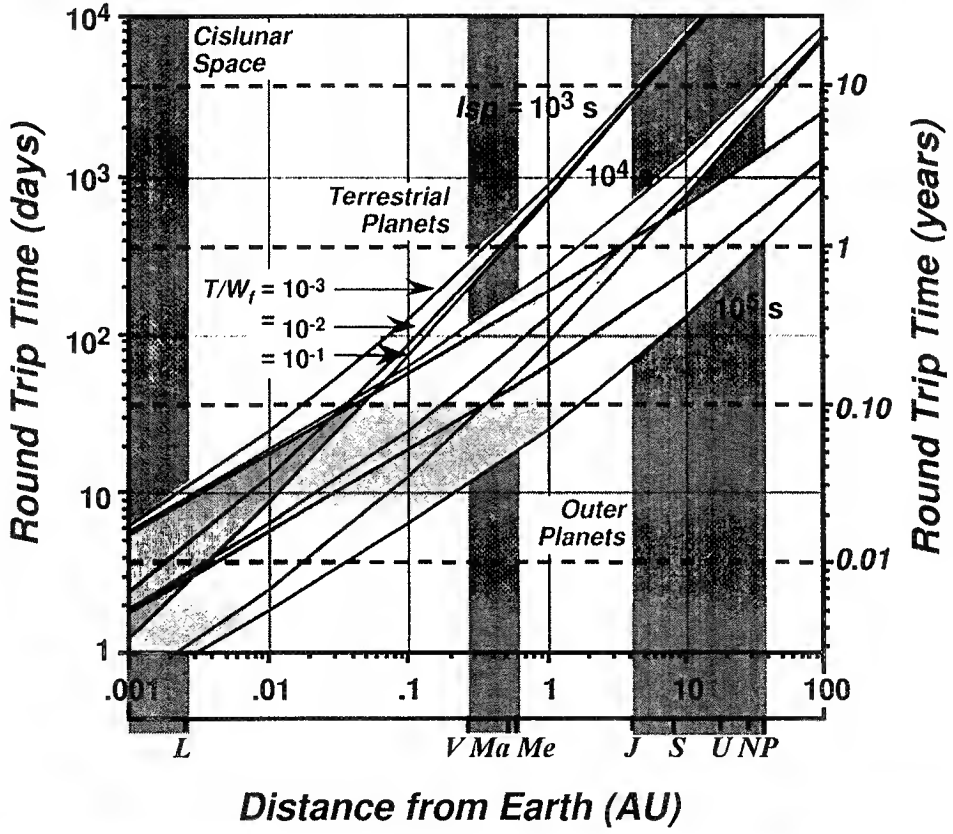


GOALS:

- *Lightweight, high-Isp systems*
- *Integrated propulsion & aerodynamics*
- *?V reductions via launch assist & offboard boost*

Research Goals - Space

Direct omniplanetary missions within 100 AU



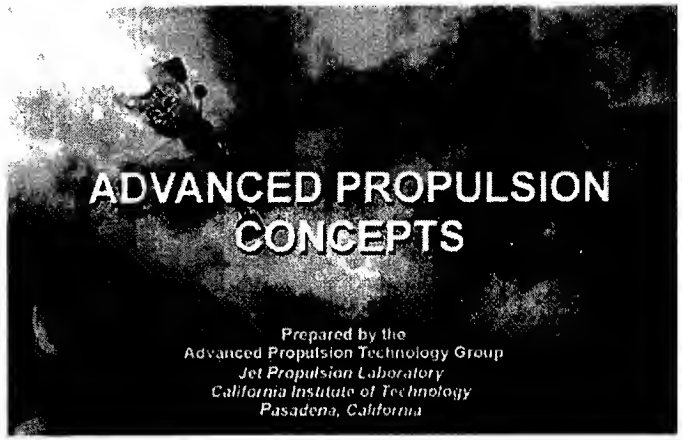
GOALS:
- *Specific impulse ($Isp = T/\dot{w}_p$) of at least 10^5 secs*
- *Vehicle accelerations (T/W) greater than 10^{-3} g*

Space Transportation Research

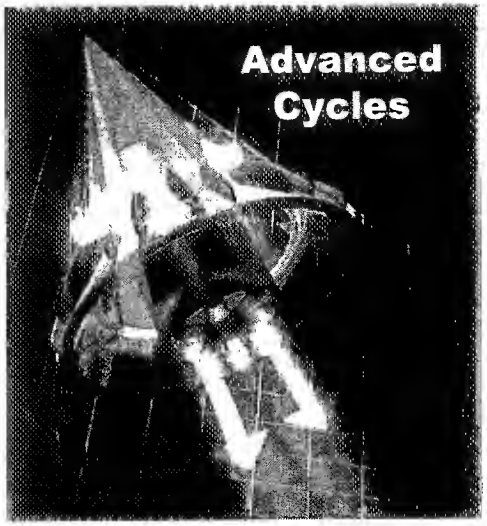
JPL

- **Advanced Propulsion Workshop**
  - 10th NASA/JPL/MSFC/AIAA Advanced Space Propulsion Concepts Workshop
  - Held at Bevill Center in Huntsville, AL April 5-8, 1999

- **Advanced Propulsion Concepts Database**
  - Now available NASA wide
  - http://sec353.jpl.nasa.gov/apc
  - General information on a wide range at advanced propulsion concepts and applications

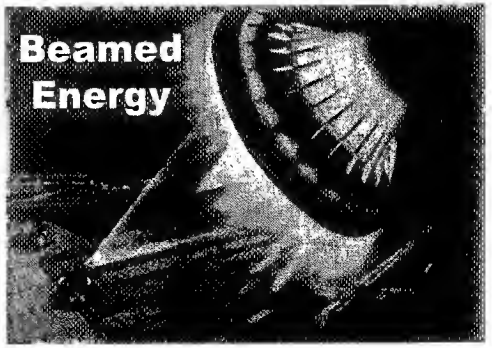


Space Transportation Research



- **Goal: Conduct research into advanced technologies that may enable dramatic high payoff improvements in space transportation**

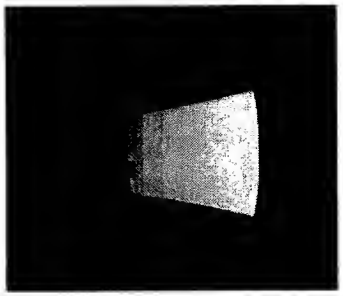
- **Initiatives:**
  - **Advanced cycles**
    - Pulse detonation wave engine
    - Fusion propulsion
    - Fission propulsion
    - Exotic fuels
  - **Off-board resources**
    - Magnetic assist launch
    - Beamed energy
    - MHD
  - **Breakthrough physics**



Space Transportation Research

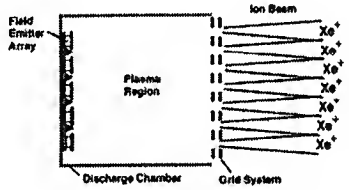
JPL

- **Lorentz Force Accelerator (LFA)**
  - Lithium fueled MPD type electric engine
  - 30 kW version delivered to Princeton for testing
  - 500 kW thruster ordered from MAI, delivery on hold due to U.S. sanctions
  - Mods to high power test chamber underway at JPL

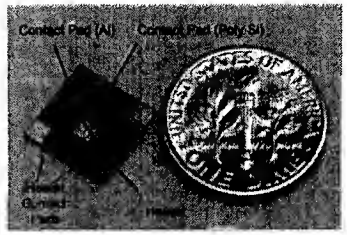


30 kW MAI Li thruster delivered to Princeton University for testing with JPL feed system

- **Micro-Ion Engine Research**
  - Performance Goals
    - Isp: ~3000 sec
    - Thrust: mN to mN
    - Power: <10 W
  - Will validate data obtained with USC/AFRL hollow anode



MEMS-Hybrid Micro-Ion Engine Concept



Test Chip to measure Electric Breakdown Characteristics of Silicon Oxide for Use in MEMS Grids

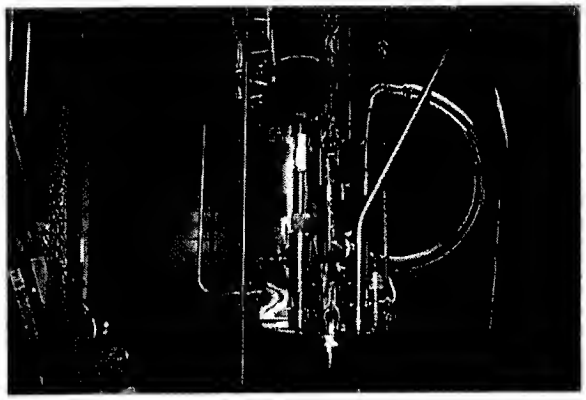
- **Fusion and Antimatter Research**
  - Penn State has made major upgrades to the portable Penning trap
  - Loaded >10^6 H-ions into trap and demonstrated 1/e lifetime of >5 days

Portable Antimatter Trap

Space Transportation Research

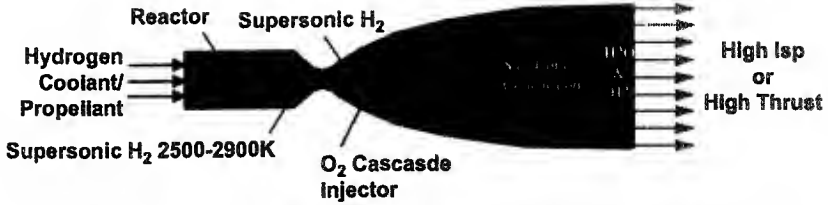
GRC

- **Atomic Propellants, Solid Hydrogen**
  - Takes advantage recombination energy of atoms of boron or carbon
  - Atoms trapped in solid hydrogen ice particles suspended in liquid helium
  - May provide very high specific impulse, Isp >750 sec
  - First test with solid hydrogen and 14 deg.K liquid helium in March 99'
  - Test with atomic constituents are still several years away at current funding levels
  - Collaboration with AFRL-Edwards



Solid Hydrogen Test Rig

- **Lox Augmented Nuclear Thermal Rocket (LANTR)**
  - Combines high thrust to weight of chemical rocket with high Isp of Nuclear Thermal Rocket (NTR)
  - Lox is injected into supersonic flow of NTR nozzle
  - Combustion adds thrust at expense of Isp
  - High thrust is needed while vehicles are in planetary gravity well
  - May begin hot fire tests in FY00



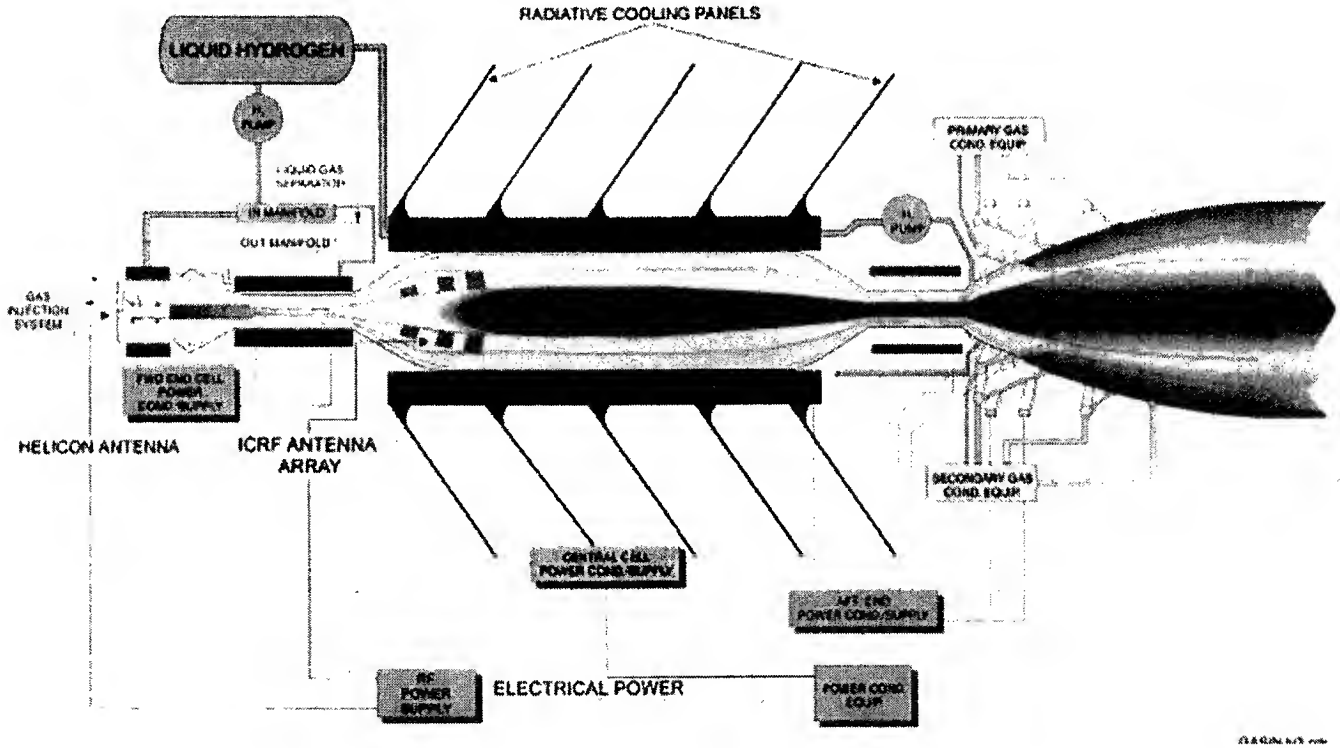
Lox Augmented Nuclear Thermal Rocket (LANTR)

Space Transportation Research

JSC

VASIMR System – Plasma Rocket

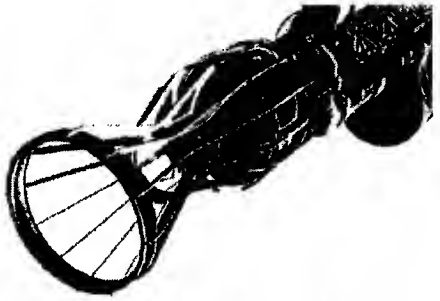
- Variable Specific Impulse (Isp) and Thrust at maximum power. Offers operational flexibility.
- Electrodeless design with magnetic insulation.
- High power density.
- Propellant is cheap and plentiful; chemical forms (Ammonia, Methane, etc.) may be easy to store and produce in-situ.
- Continuous acceleration (very low artificial g).
- High efficiency Ion Cyclotron Resonance Heating (ICRH), high voltage and low current.
- Hydrogen is aneutronic, and provides the best radiation shield to GCR and SPEs.



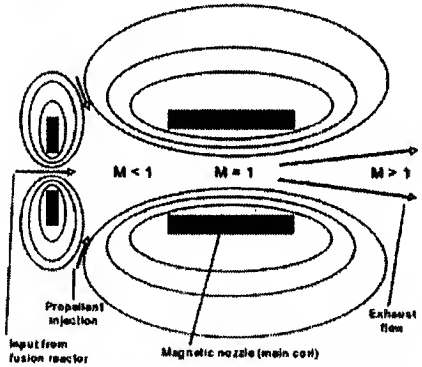
Space Transportation Research

LeRC

- **Magnetic Nozzle Experiment for Space Fusion Powered Propulsion**
  - Development of plasma source and magnetic nozzle apparatus
  - Experiments with magnetic nozzles scaled from fusion-reactor heated flows
  - Los Alamos National Lab is lead in magnetic nozzle theory development
  - Ohio State University has unique GW power level experiment test facility

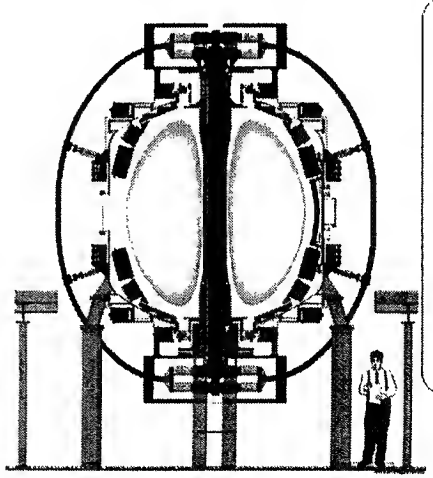


Conceptual Flight Magnetic Nozzle



Experimental Magnetic Nozzle

- **Coaxial Helicity Ejection Experiment (CHE)**
  - Utilizes Princeton Plasma Physics Laboratory (PPPL) National Spherical Torrs Experiment (NSTX) reactor
  - Ejection of plasma in toroidal reactors occurs naturally during shut down
  - Experiment using CHE operation through a divertor offers potential for extracting plasma power directly



Baseline Parameters

- Major radius ≤ 85 cm
- Minor radius ≤ 68 cm
- Plasma current 1 MA
- Toroidal field 0.3-0.6 T
- Heating and current drive 6-11 MW
- Flat-top time 5-1.6 s